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REDESIGNING THE ELEMENT PROFILE OF AIR PREHEATER IN COAL-FIRED POWER PLANTS FOR EMISSION REDUCTION AND EFFICIENCY IMPROVEMENT

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Abstract:
A state-owned company, PT PLN Nusantara Power Unit Pembangkit Tanjung Awar-Awar (UPTA), provides electricity to Java and Bali. UPTA currently has two coal-fired mills with a capacity of 350 MW each. UPTA has emphasized efficiency in its operations, modernizing machinery, and reducing emissions in recent years. Accordingly, UPTA decided to improve its air preheating element, the air preheater (APH), to heat the primary and secondary air to a temperature required for efficient combustion. The element profile was redesigned from a distorted, wavy flow path to a linear flow path to achieve optimal APH. The profile surface was coated with an "enamel" layer, which prevents ash from adhering readily. Our measurements and calculations were based on data collected in October 2022 (pre-implementation) and February to June 2023 (post-implementation). Power consumption decreased from 1740 kWh a month to 1377 - 1535 kWh a month, or 11% - 21%, for the induced draft fan (ID Fan) and from 1900 kWh a month to 1450 - 1542 kWh a month, or 19% - 29%. Also, differential pressure measurements for APH 1A and 1B declined significantly around 1000 - 1100 PA. By redesigning the element profile, it reduces greenhouse gas emissions (16.98 tons for 〖NO〗_2, 16.24 tons for 〖SO〗_2, 3.97 tons for TP, and 11,770.04 tons for 〖CO〗_2), and decreases operating costs by IDR 4,244,278,577, or around IDR 820,080,618 to IDR 922,499,613. The redesign project has positively impacted the system, the environment, and the company's profitability.

Keywords: Coal-fired power plants, Air Preheater, emissions reduction.

INTRODUCTION

The need for innovation. PT PLN Nusantara Power Unit Pembangkit Tanjung Awar-Awar (UPTA) operates within the energy sector and focuses on generating electricity using coal as the primary fuel. With a 2 x 350 MW generation capacity, the company relies on a steam model produced by heating coal as a turbine driver to produce electricity.

Following Indonesia's evolving industries, there has been an increased demand for energy supply security amidst the rise in fuel prices. UPTA implemented an innovative project to ensure the air preheater (APH) performance for optimal steam and air cycle operation in its coal-fired power plant.

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The APH constitutes crucial auxiliary equipment in a coal-fired power plant. Scientifically scrutinized, it preheats both the primary and secondary air to a temperature required to facilitate optimal combustion in the boiler. In its process, the APH utilizes the flue gas energy produced by the boiler during combustion. The heat is then gradually transferred to the airflow through the heating element (rotating heat exchanger).

The heating element is typically configured as metal plates and sectioned into two vertical parts: the upper part as a Hot End Layer and the lower part as a Cold End Layer. The metal plates are attached vertically to a rotor, which is a cylindrical compartment and divided radially. This rotor rotates around a chamber that has duct connections to two sides: one side is the exhaust gas duct, while the other contains both primary and secondary air. When the rotor is rotated, half of it is in the flow of entering the exhaust gas channel and absorbing the heat energy contained therein. The other half transfers heat from the element to the side of the air stream, thus producing hot air, which will then be supplied to the furnace.

Problem identification. Various factors may cause a decline in the performance of air preheating equipment in a coal-fired power plant. One of the underlying factors of such performance degradation is the accumulation of ash deposits or plugging in the area of the air heating element, which impairs the heat transfer process. The reduced efficiency of heat transfers caused by this accumulation causes an ineffective preheating process, and the APH cannot bring the air up to the required combustion temperature.

As a result, the Primary Air Fan (PA Fan) and Induced Draft Fan (ID Fan), which supposedly circulate air and flue gas, require more power to thrust the air and gas against the increased resistance. The power demand for driving the fans can lead to unexpectedly higher operating power consumption.

It is identified that the blocking or plugging with ash on the air side of the air preheating element causes, firstly, an increase in the differential pressure (DP) across the air preheater that makes the resistance become more significant against the airflow (input and output); secondly, both the Primary Air Fan (PA Fan) and Induced Draft Fan (ID Fan), which supposedly maintains the air circulation rates for effective combustion in the boiler, experience an increase in operating power consumption due to uneven flow of air and flue gas boiler; thirdly, the increased demand for more operating power leaves several implications on, such as higher energy costs, reduced overall efficiency of the power plant, increased fuel consumption, and more significant emissions (CO_2, NO_2 and SO_2) and other environment-associated costs resulting from the combustion process.

The redesign: from distorted, wavy flow path to linear flow path. A scientific and practical analysis found that the result of corrosion is seen in the uneven (flat) surface, which can trap more ash particles; as the particles accumulate, they can impede the airflow and thus create plugging in the APH element grille. This imposition, in consequence, creates more resistance to gas flow, meaning that fans like PA Fan and ID Fan need to work harder, require more operating power to circulate air and flue gases and reduce the efficiency of power plants.

Redesigning the profile of the APH elements is considered an effective measure to mitigate the plugging in the elements. By considering the specific conditions and challenges of the boiler operation, redesigning the element profile can significantly improve the overall performance of the coal power plant, including an increased thermal efficiency process.

Located at the plant unit of Tanjung Awar-Awar, PT PLN Nusantara Power developed an innovation by redesigning the profile of the APH element from a distorted, wavy flow path to a linear flow path. The main goal of the redesign is to simplify the air and flue gas streams across the heat exchange surface to reduce resistance and prevent blockages that can lead to inefficiency.

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During the implementation phase, the redesign involved changes to both the profile and the surface elements:

Redesign of the element profile of the air preheater. The redesign of the element profile involves changes in the structure from Double Undulated (DU) type to GEECO's High Cleanability Profile - GCP® & GCF® (GCP) type. The DU type typically consists of plates with undulated patterns, sometimes featuring two sets of corrugations. This configuration enhances the heat transfer due to increased surface area and turbulence. However, due to a potential accumulation of particulates in the crevices of the undulations, applying the DU type can be susceptible to fouling and plugging in the air preheater element.

On the other hand, the GCP type generally has smooth corrugations or a wave-like design incorporating a more streamlined flow of gases. This design type offers advantages: improved heat transfer efficiency, reduced potential fouling and plugging, enhanced thermal efficiency and fuel consumption, and lower maintenance and operating costs. However, It is worth noting that the specifics of the GCP-type design would depend upon the materials used, the patterns of corrugations, the spacing, and the dimensions. These aspects would also need to be tailored to the specific operating conditions of the plant.

The transition between these types should consider the impact on overall plant operation, including heat exchange efficiency, maintenance requirements, and any retrofitting constraints. The primary objectives of making such a change are to optimize the performance of the air preheater, reduce power consumption, enhance operational reliability, and minimize the plant's environmental impact.

Redesign of the surface element of the air preheater. In this type of redesign, an "enamel" layer, combined with the redesign of the element profile, was applied to the surface of the air preheater to give smoothness and a gap in the profile. This allows the ash residue from combustion to escape smoothly through the air preheater, preventing the plugging or accumulation of ash from combustion.

Commitment to sustainability. By implementing this efficiency-aiming redesign project, we contribute to the following aspects:

1) Machinery system: By improving air preheater (APH) to preheat primary and secondary air, the coal combustion can run very effectively with minimum leakage in the boiler area. Our redesign project has helped reduce the average power consumption by up to 29% per month, and thus decrease the use of coal weight of nearly 4 million kg, compared to the pre-installation period (see section **4. Implementation and Result**)
2) Environment: We believe that the energy savings incentivized by this project play an essential contribution to climate change mitigation (greenhouse gas (GHG) emission reduction) initiatives, as echoed by many climate scientists and international communities and is aligned with the objective of the PROPER program adopted through a Regulation of Minister of Environment and Forestry No. 1/2021 to encourage companies to undertake sustainable business practices beyond compliance standard. Our project has made progress toward Indonesia's commitment to reduce its GHG emission target by 31.89%, or around 912 million tons of CO_2 in 2030, as stated in its Nationally Determined Contribution (NDC).
3) Economic value: The project has had a profitability impact on the company based on the operation's reduced power and coal consumption. After the project implementation, an overall cost savings was over IDR 4 billion (USD 264,700). This is indeed considered another important reflective outcome of such a redesign project.

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Coal-fired power plants. As a type of thermal power station, coal-fired power plants rely on coal combustion to produce steam, which is used for technological processes in driving turbines for electricity generation. Coal reserves are limited in nature as a fossil fuel but have a higher power density than renewable energy sources like solar and wind. This fact makes coal a reliable energy source and an attractive option because of its abundance and relatively low price. However, there are some disadvantages of using coal as the primary fuel: 1) pollutants are emitted into the atmosphere due to coal combustion, 2) coal-fired power plants use huge volumes of water in their operations, and 3) coal combustion produces ash.

Air Preheater (APH). The APH is crucially needed for technological processes in steam power plants like coal-fired plants to improve combustion efficiency and reliability and attain an ideal balance between fuel consumption and energy output. As primarily used in coal-fired power plants, the coal fuel is burned to produce steam. The air preheater preheats the combustion air prior to entering the furnace. An air preheater recovers waste heat from the flue gases, which, in effect, can increase the boiler's efficiency and save the residual heat from the combustion exhaust gas. By transferring heat from the exhaust gases of the power plant to the combustion air, the preheater raises the air temperature. It reduces the heat needed to increase the fuel temperature. By preheating the combustion air, the air preheater improves efficiency and reduces fuel consumption.

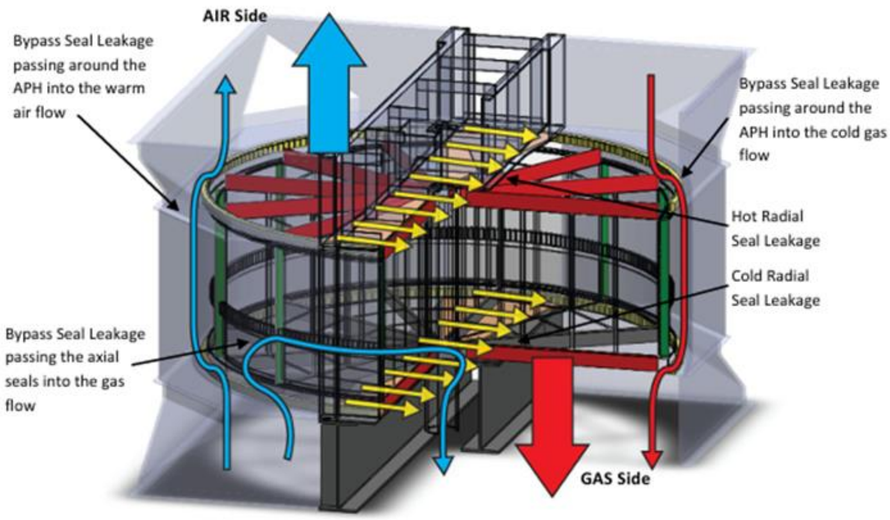

Figure 1. A leakage through an air preheater that occurs circumferentially [7]

Figure 1 shows that each end of the air preheater rotor has circumferential seals around the circumference. During a short circuit around the APH, the leakage from the inlet side of circumferential seals will bypass the heat transfer element and escape through the downstream seals. The leakage also leads to enthalpy loss in the element bundle. Furthermore, gas entering the ID Fans is heated and getting more significant. The first set of circumferential seals in the air preheater will leak volume into the annulus around the rotor perimeter. Here, the leakage splits into two directions. The differential pressures at exit points determine the volume in each direction. Some flow will continue straight through the second set of circumferential seals. The rest of the flow will escape the air preheater through the gas side-cold end circumferential seals and enter the exhaust gas stream through the axial seals.

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Emission factors. Emission factor (EF) is a value that represents the correlation between the quantity of pollutants released into the atmosphere and an activity that causes pollution to be released. EFs are used to calculate the GHG emissions of a particular process or activity.

Table 1. Emissions factor 2023

Chemical Compounds (Ch)	Term of abbreviation	Emission Factor (Ef) /Ton/kWh
NO_2	Nitrogen Dioxide	0.000002800
SO_2	Sulfur Dioxide	0.000002679
TP	Total Particulate	0.000000655
CO_2	Carbon Dioxide	0.001941208

As Table 1 shows, emission factors represent the amount of pollutants released into the air. Information provided in the table can help policymakers develop emission reduction strategies by identifying the areas that need improvement. Emission factors are crucial for designing sustainable business practices, considering the adoption of either renewable or green energy production, and, most importantly, understanding the environmental impacts of industrial activities, particularly those related to coal mining and coal-fired power plants. By understanding the emission factors, policymakers can decide whether to incentivize industries for their success in reducing emissions through a carbon pricing mechanism.

High temperatures, such as those in industrial processes, power plants, and vehicle exhausts, produce Nitrogen Dioxide (NO_2). Experts estimate that coal emissions have been linked to respiratory effects such as lower respiratory disease, coughing, wheezing, and shortness of breath. Long-term exposure to NO_2 may adversely increase respiratory infections. Sulfur Dioxide (SO_2) emitted into the atmosphere due to fossil fuel combustion, including coal, oil and natural gas, contains a respiratory irritant that can lead to diseases such as asthma, chronic bronchitis, and pneumonia. High exposure to SO_2 can also irritate the eyes, nose, and throat. Total Particulate (TP) refers to a sample's total amount of phosphorus. Increasing phosphorus levels can lead to eutrophication, characterized by excessive algae and other aquatic plant growth. This is to say that water quality is impaired due to decreased oxygen levels. Carbon Dioxide (CO_2) is produced from the burning of fossil fuels and from deforestation activities, as well as from the respiration of living beings and volcanic eruptions. In other words, human activities are also contributors to CO_2. All of these activities have increased their concentration. As a result, global temperatures rise, and extreme weather events occur due to climate change. The concentration of CO_2 has also caused ocean acidification.

METHODS

Figure 2 shows the flow of how the air preheater is redesigned. First, inspection and examination are our routine processes to ensure the power plant works accordingly. Any faults and potential issues are systematically scrutinized and evaluated in this process. There are two common types of inspection: visual inspection and functional testing. Visual inspection uses physical examination to identify potential defects, damages, or abnormalities through physical examination. At the same time, functional testing involves testing functionality or performance. Data collection is crucial to the design and development of an APH. We collect various types of data to ensure a comprehensive analysis, including 1) environmental data: we gather information about environmental conditions such as temperature, humidity, and wind speed; 2) flow and pressure

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data: we measure and analyze the flow and pressure characteristics of the airflow through the APH; 3) heat transfer data: we measure and analyze the heat-transfer coefficient and efficiency of the APH; and 4) maintenance and operational data: we collect data on existing air preheaters' maintenance requirements and operational efficiency. We designed the APH element consisting of a series of parallel plates arranged in a bundle. The plates are typically made of metals, usually corrugated, to increase the heat transfer surface area.

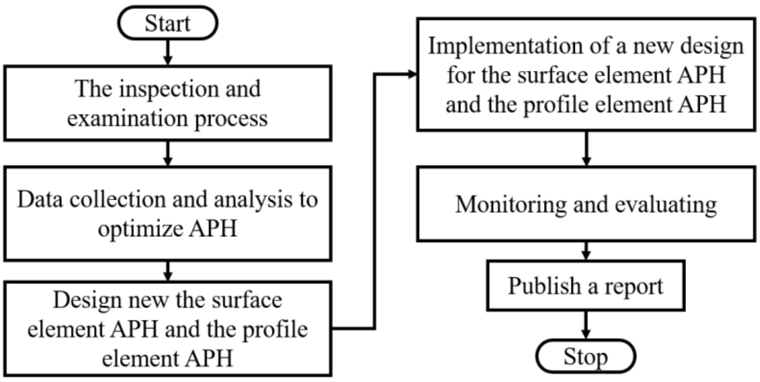

Figure 2. Air preheater redesign flowchart

Our redesign project design aims at: 1) improving energy efficiency: by preheating the air, the amount of energy required for combustion is reduced; 2) enhancing the combustion process: the preheated air, which is at a higher temperature, can improve the ignition and combustion of the fuel in the boiler; and 3) reducing pollution: the preheated air helps reduce the formation of harmful pollutants. Implementing the air preheater design involves several steps, including defining the application, conducting the heat transfer analysis, testing the factory acceptance, and installing the preheater. To complete these steps, monitoring and maintenance are essential to keep the preheater's performance and lifespan. For the report, we will present an analysis of the data results obtained from the new APH implementation. The analysis aims to see the difference before and after installation (pre- and post-implementation). Also, it is worth knowing about the implications of the redesign project – whether further research-based investigation and validation against the findings is necessary for us to undertake in the future.

PA Fan and ID Fan air circulation. To support the boiler's air preheating cycle and flue gas, UPTA Unit 1 has two sides of air preheaters, APH 1A and APH 1B (see Figure 3). Likewise, the PA Fan and ID Fan have two sides in the air preheater trend line: PA Fan 1A and 1B and ID Fan 1A and 1B. The two sides of air heaters play critical functions, such as preheating the air and reducing emissions. The side air preheaters can improve combustion efficiency, reduce fuel consumption, and contribute to a greener and more sustainable power generation process by preheating the incoming air. PA Fan supplies air needed for effective coal combustion in the boiler, thus creating steam, which is then used to generate heat. In the mechanical process, coal is pulverized to an excellent particle size to be introduced directly into the boiler for combustion. On the other hand, the ID Fan is designed to draw air or gas into the system, typically through a furnace or combustion chamber. As a result, it enables a continuous flow of air or gas, allowing for a controlled combustion.

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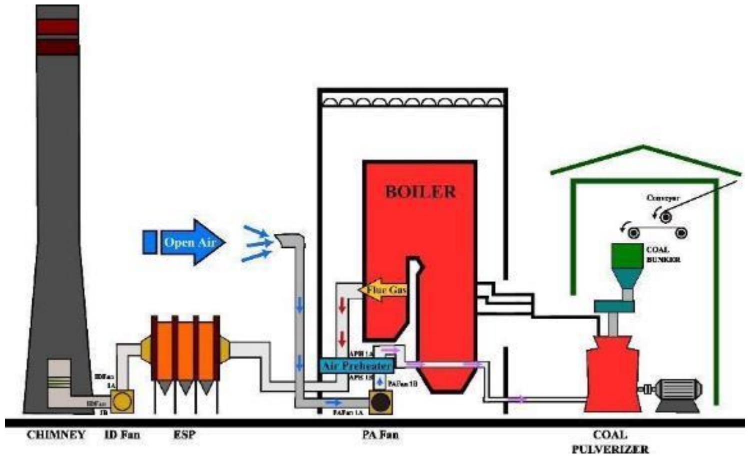
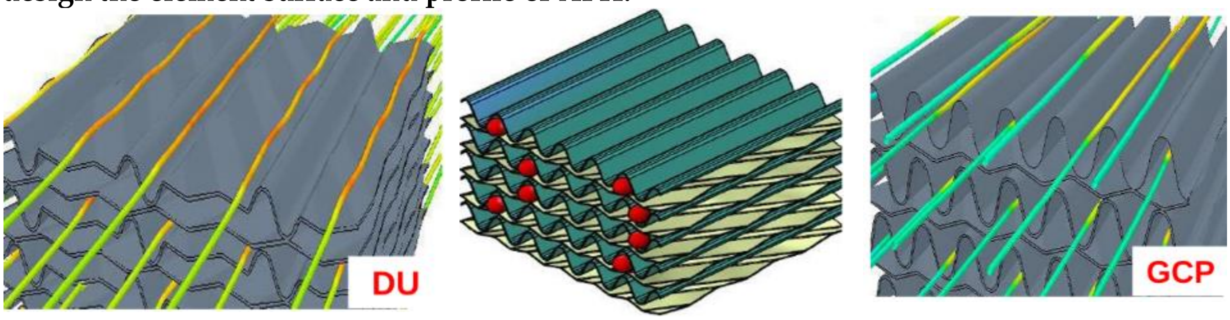


Figure 3. Air circulation and flue gas in the boiler

Redesign the element surface and profile of APH.



(a) Distorted Wavy Flow Path (DWFP)

(b) Large ash particles can pass through without choking the heating elements

(c) Linear Flow Path (LPH)

Figure 4. The form of the APH element profile

The redesign project mainly focused on changing form from a distorted, wavy flow path (DWFP) to a linear flow path (LFP), as shown in Figure 4. The above pictures show the process of air passing through the element profile. APH elements have been based on the Double Undulated (DU) element profile for many years. The DU flow path in the air preheater utilizes DWFP to achieve enhanced heat transfer performance. We changed the element profile to a linear flow path system for efficiency and circulation improvement. The air moves in a specific direction in linear flow paths, typically through ductwork or other channels. The air preheater operates according to the heat exchanger principle. The flue gas exits through the furnace, typically at a high temperature, and flows through the heat transfer elements. These elements are mainly equipment where heat is transferred to the air flowing through it. Afterward, the preheated air is returned to the furnace to help with combustion. With the change we made, we can see two main improvements in the aftermath:

1. The APH element profile will be redesigned from DU to GEECO's High Cleanability Profile—GCP® & GCF® (GCP). This change aims to improve air and flue gas circulation and heat exchange.
2. Redesign the surface element of the APH: We replaced the previous surface layer of the air preheater, where the previous air heating element had no layer, in order to allow ash to stick onto the surface quickly. An "enamel" layer was added and applied on the air preheater profile

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surface to give smoothness and gap, allowing the combustion ash to escape through the air preheater easily. By doing so, it prevents combustion ash from plugging or accumulating.

Mathematical analysis formula for comparison. Mathematical analysis compares the efficiency and environmental impact of the system before and after installing the upgraded APH. The formulas can be found as follows:

$$P_{PA_{Fan}} = \sqrt{3}.V.I.Cos_{phi} \times 0.0036 \qquad (1)$$

$$G_{P_{dec}}(m) = T_{B_{APH}} - T_{A_{APH}}(m) \qquad (2)$$

Where $P_{PA_{Fan}}$= FAN Power, V= voltage, I = current, 0.0036 GJ = conversion from 1 kW. Our calculation considers the device's energy consumption. We evaluate a device's effectiveness and efficiency by analyzing its power consumption and output.

Where $G_{P_{dec}}(m)$ = Power Reduction Gap, $T_{B_{APH}}$ = APH before reverse engineering, $T_{A_{APH}}$ = APH after reverse engineering. By calculating the Power Reduction Gap, we identified areas where power reduction techniques have effectively reduced electronic device power consumption.

$$P_{sv}(m) = \; G_{P_{dec}}(m) \times h_d \times d(m) \qquad (3)$$

Where $P_{sv}(m)$ =total power savings for one month, h_d is the total number of hours in one day in 24-hour mode, *and* $d(m)$ is the total number of days in the month. By calculating total power savings within one month, we determine the reduction in energy consumption resulting from various measures taken during the calculating period. In addition, we can identify which areas need improvement. This has enabled us to implement energy-saving measures.

$$W_r(Ch)(m) = P_{sv}(m) \times Ef(Ch) \qquad (4)$$

Where Ch = chemical compound as seen in Table 1, $W_r(Ch)(m)$ = the emission reduction for specific Ch in m (month), $Ef(Ch)$ = emission factors for specific Ch. The emission reduction is calculated to assess the effectiveness and impact of climate mitigation strategies, create international cooperation, inform policy development and implementation, and provide economic profitability.

$$Cost_{P_{sv}}(m) = P_{sv}(m) \times Price_e(m) \qquad (5)$$

$Cost_{P_{sv}}(m)$ = cost power savings, $Price_e(m)$ = the electric price in kWh for m (month). The calculation of power saving uses the price form. This is to simplify power usage reduction calculation. In 2023, kWh's electric price was IDR 700/kWh.

$$SFC = W_{coal(kg)}/G_e \qquad (6)$$

Where SFC = specific coal consumption, $W_{coal(kg)}$ = the weight of coal in kg, and G_e = the generated electricity. Specific coal consumption measures coal-fired power plant efficiency and quality. UPTA currently has an SFC value of 0.62 kg/kWh. It serves as a critical indicator for determining the environmental impact of electricity generation and guiding any efforts to reduce greenhouse gas emissions. Improvements in coal consumption can help power plants become more sustainable and environmentally friendly.

$$WP_{sv(coal)}(m) = SFC * P_{sv}(m) \qquad (7)$$

Where $WP_{sv(coal)}(m)$ = the saving of coal weight in m (month), accurately monitoring coal weight can optimize coal usage, reduce waste, and improve overall operation efficiency. The way

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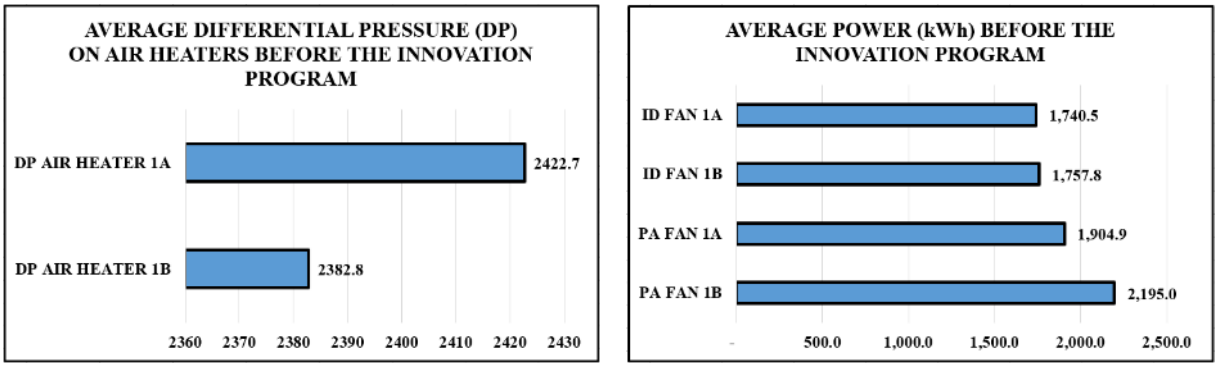
we calculated this also enabled us to assess the benefits of coal weight optimization strategies for financial decision-making.

RESULT AND DISCUSSION

We measured Differential Pressure (DP) on Air Preheaters 1A and 1B and the average electrical power consumption of PA Fan 1A and 1B and ID Fan 1A and 1B before the innovation program was implemented in September - October 2022. Figure 5 shows that the differential pressure of the air preheater has encountered blocking (>2000pa) and average electrical consumption on both the PA and ID fans.



(a) Average DP APH Sept - Oct 2022 (b) Average Power (kWh) Sept-Oct 2022

Figure 5. Average DP and power before the new design element profile of APH was implemented

It was found that power consumption, emissions, and energy consumption are related to the combustion process. Factors contributing to this complexity include fuel, combustion efficiency, and emissions control technologies. Higher electrical power is required to increase the operating power of the PA Fan and ID Fan. For example, if both the PA fan and ID fan operate at 10% higher power levels, the overall combustion process electricity demand will rise by around 10%. This increase in electrical power leads to a corresponding increase in fuel consumption when generating power, consequently increasing combustion emissions. Figure 5 shows that DP AIR HEATER 1A and 1B are high, exceeding 2000 PA. When the airflow is not correctly flowing in DP AIR HEATER 1A and 1B, the result will be higher energy costs. There is an average power of more than 1,700 kWh for the ID Fan and more than 1,900 kWh for the PA Fan. Based on this measurement, improvements must be made to make them more effective and efficient. In addition, to reduce the operating cost associated with the overall process, the fans must also be optimized to allow the airflow to be directed appropriately, thus reducing energy consumption.

Figure 6 shows that the preheater has a problem of blocking ash particles from the combustion chamber, which are easy to accumulate and block up. If the ash blocking becomes severe, it reduces heat transfer efficiency with the decreased airflow of the air preheater, increases fuel consumption, and causes an inconsistency in temperatures, which threatens the overall operation and performance of the air preheater.

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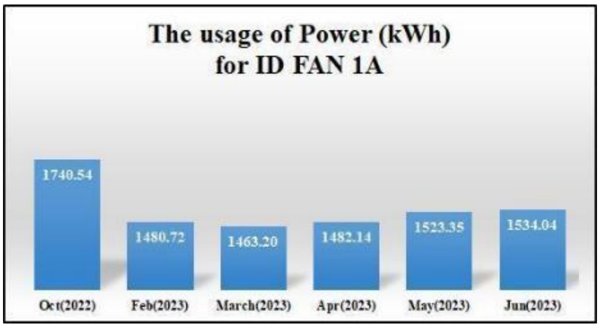
Figure 6. Ash particles carry over to air preheater


Figure 7. Implementation of a new element of air preheater

A new element profile in APH Unit 1 was installed during our overhaul in November 2022 (Figure 7). The element profile was replaced from DU with GCP. The DU used a distorted asymmetric flow path system, while the GCP now uses a linear flow path system with an added enamel layer. This work was completed in January 2023.



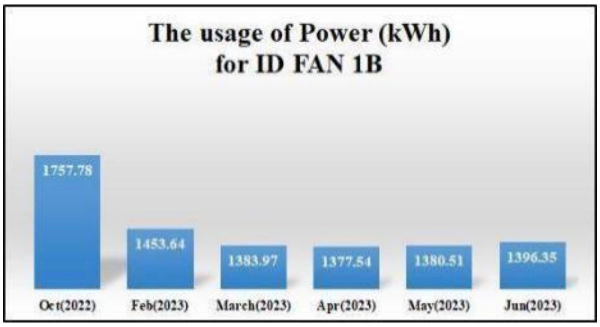


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Figure 8. The average power consumption before and after the installation of the new APH element profile

The average power consumption was reduced when the GCP for APH was installed in the system. As shown in Figure 8, the average power consumption was higher in October 2022 (pre-installation) compared to February to June 2023, when the new APH element profile was completely installed. Before the installation, power consumption was consistently high, with more than 1740 kWh for the ID Fan per month and over 1900 kWh for the PA Fan per month. After the installation, the new APH element profile significantly reduced the average power consumption to around 1377 - 1535 kWh (11% - 21%) for ID Fan per month and 1450 - 1542 kWh (19% - 29%) for PA Fan per month, which indicates that the newly installed system causes more efficient in energy consumption and reduces a significant amount of emission. Fewer fossil fuels are burned to supply electricity, heat, and transportation. It helps reduce our carbon footprint from GHG emissions and mitigate climate change.

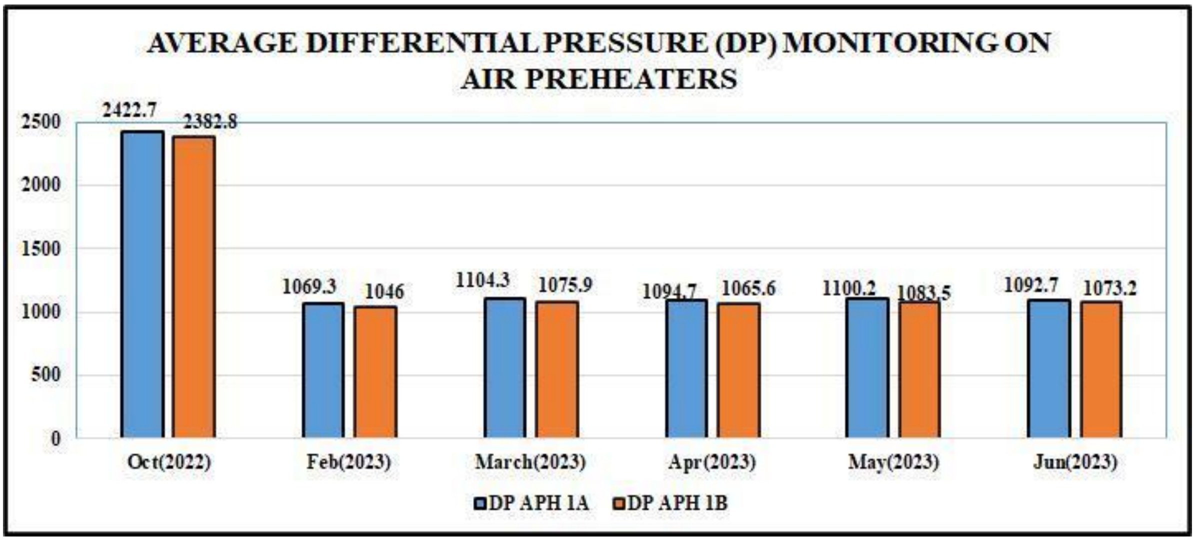

Figure 9. Average DP monitoring on-air preheater (APH)

Another efficiency measure can also be seen in the average differential pressure (DP) for APH Unit 1A and 1B, which drastically dropped from 2300 - 2400 pa before the installation in October 2022 to 1000 - 1100 pa after the installation between February and June 2023. The difference can be seen in Figure 9. When the average DP drops in number, the APH works experience improvement in terms of efficiency. Also, when the equipment works properly, it mitigates the potential blocking in the duct and causes a decrease in air leakage.

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Table 2. Power usage in October 2022 (pre-installation)

	Equipment	Voltage (V)	Current (I)	Cos Phi	Power (kW)	Power (GJ)
1	ID FAN 1A	6,300.75	196.9	0.81	1,740.54	6.27
2	I FAN 1B	6,308.15	201.1	0.8	1,757.78	6.33
3	PA FAN 1A	6,300.75	198.5	0.88	1,906.32	6.86
4	PA FAN 1B	6,308.15	227.6	0.88	2,188.35	7.88
			Total power		**7,592.99**	**27.33**

Table 2 shows that the ID fan and PA fan's instantaneous power consumption was 7,592.99 kW before the installation in October 2022. The value is calculated from the total amount of power consumed by the two fans and measured in kW to provide a real-time account of the fans' energy use.

Table 3. Total power savings in February 2023 (post-installation)

	Equipment	Voltage (V)	Current (I)	Cos Phi	Power (kW)	Power (GJ)
1	ID Fan 1A	6,265.5	168.45	0.81	1,480.72	5.33
2	ID Fan 1B	6,282.65	166.98	0.8	1,453.64	5.23
3	PA Fan 1A	6,265.5	152.77	0.88	1,458.94	5.25
4	PA Fan 1B	6,282.65	152.08	0.88	1,456.32	5.24
		Total power			**5,849.63**	**21.06**
		Power reduction gap			**1,743.37**	**6.28**
		Total power savings for Feb 2023			**1,171,543.74**	**4,220.16**

Table 4. Total power savings in March 2023 (post-installation)

	Equipment	Voltage (V)	Current (I)	Cos Phi	Power (kW)	Power (GJ)
1	ID Fan 1A	6,204.64	168.09	0.81	1,463.20	5.27
2	ID Fan 1B	6,203.68	161	0.8	1,383.97	4.98
3	PA Fan 1A	6,204.64	156.58	0.88	1,480.80	5.33
4	PA Fan 1B	6,203.68	157.97	0.88	1,493.71	5.38
		Total power			**5,821.68**	**20.96**
		Power reduction gap			**1,771.31**	**6.38**
		Total power savings for March 2023			**1,317,856.59**	**4,746.72**

Table 5. Total power savings in April 2023 (post-installation)

	Equipment	Voltage (V)	Current (I)	Cos Phi	Power (kW)	Power (GJ)
1	ID Fan 1A	6,214.69	169.99	0.81	1,482.14	5.34
2	ID Fan 1B	6,241.16	159.29	0.8	1,377.54	4.96
3	PA Fan 1A	6,214.69	162.83	0.88	1,542.40	5.55
4	PA Fan 1B	6,241.16	163.1	0.88	1,551.54	5.59
		Total power			**5,953.62**	**21.44**
		Power reduction gap			**1,639.38**	**5.90**
		Total power savings for April 2023			**1,180,351.30**	**4,248.00**

Table 6. Total power savings in May 2023 (post-installation)

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	Equipment	Voltage (V)	Current (I)	Cos Phi	Power (kW)	Power (GJ)
1	ID Fan 1A	6,219.57	174.58	0.81	1,523.35	5.48
2	ID Fan 1B	6,205.52	160.55	0.8	1,380.51	4.97
3	PA Fan 1A	6,219.57	161.75	0.88	1,533.37	5.52
4	PA Fan 1B	6,205.52	160.12	0.88	1,514.49	5.45
			Total power		**5,951.73**	**21.43**
			Power reduction gap		**1,641.27**	**5.91**
		Total power savings for May 2023			**1,221,102.71**	**4,397.04**

Table 7. Total power savings in June 2023 (post-installation)

	Equipment	Voltage (V)	Current (I)	Cos Phi	Power (kW)	Power (GJ)
1	ID Fan 1A	6,258.18	174.72	0.81	1,534.04	5.52
2	ID Fan 1B	6,283.36	160.38	0.8	1,396.35	5.03
3	PA Fan 1A	6,258.18	160.88	0.88	1,534.59	5.52
4	PA Fan 1B	6,283.36	156.59	0.88	1,499.68	5.40
			Total power		**5,964.66**	**21.48**
			Power reduction gap		**1,628.33**	**5.86**
		Total power savings for June 2023			**1,172,400.77**	**4,219.20**

Tables 3, 4, 5, 6, and 7 show the total power savings achieved from February to June 2023. The total reduction gap is the difference between the total power before a new element profile is installed and the power of the present month. This gap provides insights into the potential energy savings or performance improvement from installing an upgraded element profile. A considerable reduction gap can be seen in every table. Take an example in Table 3. The power reduction gap in February was 1,743.37 kW, from which the total power saving was made for 1,171,543.74 kW. This calculation shows that when the element profile is upgraded, the energy consumption is significantly reduced, and emission is minimized.

Table 8. The environmental impact after replacing the APH element profile

Month	Power saving in a month		NO_2 (Ton)	SO_2 (Ton)	TP (Ton)	CO_2 (Ton)	Cost power savings (IDR)
	Power (kW)	Power (GJ)					
Feb-23	1,171,543.74	4,220.16	3.28	3.14	0.77	2,274.21	820,080,618
Mar-23	1,317,856.59	4,746.72	3.69	3.53	0.86	2,558.23	922,499,613
Apr-23	1,180,351.30	4,248.00	3.30	3.16	0.77	2,291.31	826,245,910
May-23	1,221,102.71	4,397.04	3.42	3.27	0.80	2,370.41	854,771,897
Jun-23	1,172,400.77	4,219.20	3.28	3.14	0.77	2,275.87	820,680,539
Total	**6,063,255.11**	**21,831.12**	**16.98**	**16.24**	**3.97**	**11,770.04**	**4,244,278,577**

Table 8 shows the environmental impact after replacing the element profile of APH. The total emission reduction calculated between February and June 2023 for NO_2 is 16.98 tons, SO_2 is 16.24 tons, TP is 3.97 tons, and CO_2 is 11,770.04 tons. The overall cost from the power savings is IDR 4,244,278,577, which means the company can reduce its operational expenses to around IDR 820,080,618 to IDR 922,499,613 per month.

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Table 9. Power savings for the month toward the reduction of coal consumption

Month	Power saving for a month		SFC	saving of the coal weight (kg)
	Power (kW)	Power (GJ)		
Feb-23	1,171,543.74	4,220.16	0.62	726,357.12
Mar-23	1,317,856.59	4,746.72	0.62	817,071.09
Apr-23	1,180,351.30	4,248.00	0.62	731,817.81
May-23	1,221,102.71	4,397.04	0.62	757,083.68
Jun-23	1,172,400.77	4,219.20	0.62	726,888.48
Total	**6,063,255.11**	**21,831.12**		**3,759,218.17**

Table 9 shows the power savings related to reducing coal consumption. In coal-fired power plants, the reduction in power consumption impacts the amount of coal used. UPTA currently has an SFC value of 0.62 kg/kWh, resulting in total coal weight savings of 3,759,218.17 kg between February and June 2023.

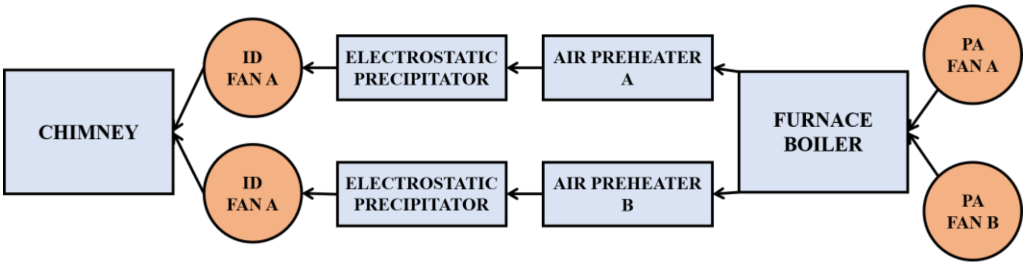

Figure 10. Workflow of air preheater (APH)

Figure 10 shows the APH workflow. Starting from the right side of the figure, the system begins its process with PA FAN followed by a furnace boiler, APH, electrostatic precipitator, ID Fan, and chimney. Here, we explain the conditions prior to and after the installation of the APH element profile:

Pre-implementation. The incoming and outgoing air passing through APH A and B have higher differential pressure levels.

Consequently, the equipment directly introduced to the APH circulating the air and flue gas experiences increased operating power. The uneven flow of air and flue causes this.

An increase in power consumption for PA and ID Fans is directly associated with higher electricity consumption. The amount of fuel consumption is proportionally linked with the capacity for generating electricity in which pollutants are emitted to the atmosphere during coal combustion.

Post-implementation. As a result of the implementation of the system, the differential pressure levels of APH Unit 1A and 1B decreased drastically. Furthermore, the average power consumption of PA Fan and ID Fan equipment also decreases.

Every reduction in power consumption significantly contributes to emission reduction because electrical energy is greatly influenced by the amount of fuel consumed. Reducing electrical energy can decrease fuel consumption, and emissions from coal combustion in the boiler can be minimized.

When coal-fired power plants operate efficiently, electricity can be produced well and securely supplied to the customer.

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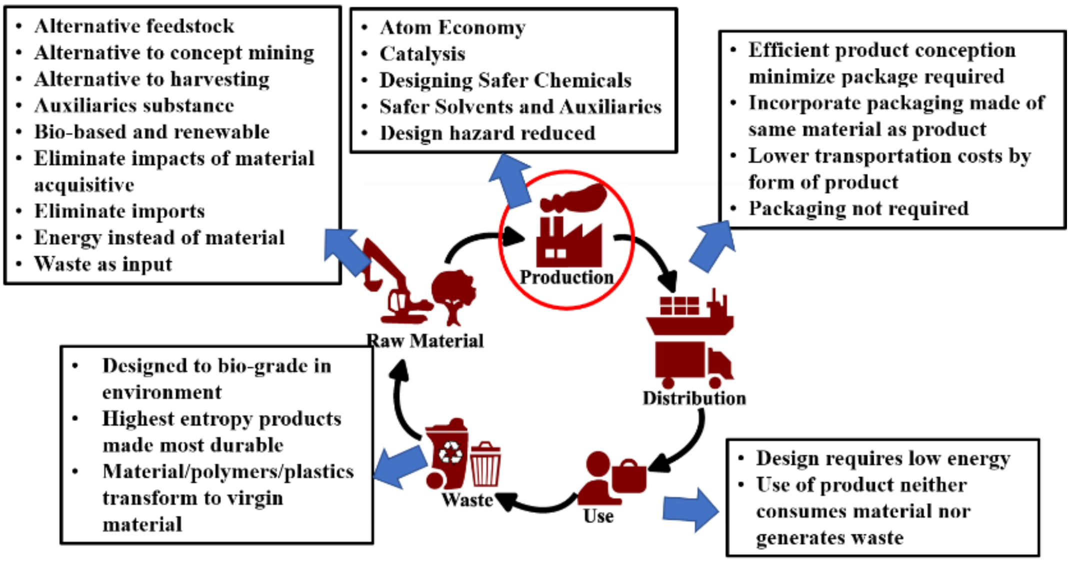

Figure 11. Potential areas for improvement as a result of implementation

We identify potential areas for improvement in the product's performance to mitigate adverse environmental impacts caused by the power plant's operation. In this project, we improve the equipment for producing a power plant by redesigning the profile element. Figure 11 shows the implementation of the new design involving environmental improvement in atomic economics, catalysis, safer chemicals, and hazard reduction in sub-focus areas. This effort has significantly decreased energy consumption, carbon emissions, and other pollutants. This has helped create a greener and more sustainable environment while reducing costs and improving the company's profitability.

Moreover, the new system is easier to maintain and troubleshoot, making the production process more efficient and cost-effective. We apply a cradle-to-grave model as a scientific Life Cycle Analysis (LCA) method. The LCA comprises five "life cycle stages," including raw material, processing, transportation, usage and waste disposal. Based on those five phases, we measured the environmental impacts and calculated the product's total carbon footprint. Compared with the old system, the new system has significantly lowered the environmental impacts, especially in the production phase, where the redesigned element profile is installed on a processing machine.

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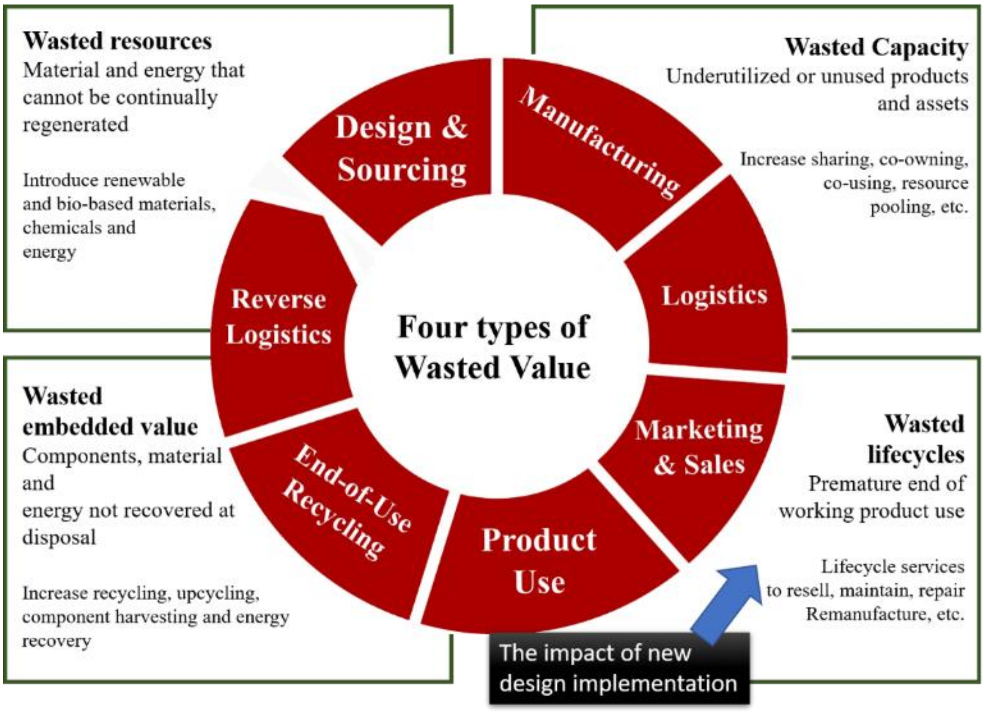

Figure 12. Four categories of waste

As shown in Figure 12, in the circular business model, there are four categories of waste: wasted resources, wasted capacity, wasted embedded value, and wasted life cycles. Wasted resources are materials and energy that are not recoverable for effective future use, such as fossil fuels. Wasted capacity is defined as an unutilized product and asset. A wasted life cycle is when a product is discarded prematurely due to improper design or lack of options for reuse. Waste embedded value refers to any materials, components, and energy not recovered from disposed things and put back into use for new value. Linking this circular concept to our project, the outcome of installing a new design is to reduce wasted heat and energy associated with the processing phase. Based on the circular model defined above, our redesign project goes to the category of the wasted life cycle because we reuse flue gas heat to heat the air passing through the APH, and the circular heat minimizes the unused lifecycles by extending the APH lifespan and decreasing premature disposal. Reduced wasted heat and energy is associated with the operating process. However, the success of the redesign project contributes to a more efficient use of resources and provides a sustainable solution through carbon footprint reduction.

CONCLUSION

Based on the routine inspections and examinations we conducted at the coal-fired power plant, we concluded that significant improvement is necessary. Our goal is to save costs, conserve fuel sources, reduce emissions and minimize damage. Therefore, we focused on improving the components in the boilers and the air preheater (APH) area. APH is auxiliary equipment in coal-fired power plants that heat primary and secondary air to a specific temperature to ensure adequate combustion. To optimize the APH, we redesigned the element profile of APH from a distorted, wavy flow path to a linear flow path. We then added an "enamel" layer to the profile surface to prevent ash from sticking quickly onto the profile surface. This method reduces power losses and APH efficiency.

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Optimizing the element profile also minimizes corrosion, leakage, and maintenance. According to the mathematical calculation, there has been an improvement by comparing conditions prior to (in October 2022) and after the installation (February to June 2023) of APH. Before the installation, the average power consumption was over 1740 kWh for the ID Fan per month and over 1900 kWh for the PA Fan per month. After the installation, we discovered that such consumption was reduced to around 1377 - 1535 kWh (11% - 21%) for ID Fan per month and around 1450 - 1542 kWh (19% - 29%) for PA Fan per month. Parallelly observed, the DP measurements for APH Unit 1A and 1B dropped drastically by around 1000 - 1100 PA differences. This indicates increased APH's efficiency and positive environmental impact after installation. Within the same timeframe, it was calculated that GHG emissions were reduced, namely NO_2 for 16.98 tons, SO_2 for 16.24 tons, TP for 3.97 tons, and CO_2 for 11,770.04 tons. The project benefited the company for its overall cost saving at IDR 4,244,278,577, or around IDR 820,080,618 to IDR 922,499,613 per month. Based on the measurements and calculations, we conclude that the improvement positively impacts the machine's system, the environment, the company's economic aspect, and the customer's satisfaction, an essential part of today's business consumer trends.

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